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Distributed Intelligent RFID Systems

Dilip B. Kotak
School of Engineering Science
Simon Fraser University
Burnaby, BC, Canada
dilip.kotak@ieee.org

William A. Gruver
School of Engineering Science
Simon Fraser University
Burnaby, BC, Canada
gruver@cs.sfu.ca

Abstract—**The major impetus for the use of RFID technology is tracking personnel and objects to monitor and control movement. Traditionally, this task is accomplished using a centralized systems architecture in which every event is transmitted to a host computer for validation.**

Distributed intelligent systems are based on two principles: distributed communications and distributed intelligence. Together, these functionalities enable the implementation of networks that are highly robust, scalable, flexible, and facilitate their integration with client/server systems.

We describe how RFID can be implemented using distributed intelligent systems to automate data collection for service queues, track and control personnel and goods, monitor and control inventory, and use dynamic digital signage for information dissemination.

Keywords—**RFID, distributed intelligence, distributed communications, holonic systems, peer-to-peer networks, automated data collection, dynamic digital signage.**

I. Introduction

Widespread commercial adaptation of RFID has accelerated during the last decade because it is a significant improvement on the functionality of bar-code technology and enables new possibilities. Advantages of RFID include:

- Non line-of-sight requirements, thus eliminating the need for alignment of tags and readers;
- Automating tag reading without human intervention;
- Ability to write information on tags.

Because RFID readers do not require line-of-sight, it is possible to place antennas and readers in locations that are more secure and inconspicuous, thereby enabling applications that are not possible or difficult to implement with bar-code technology.

RFID systems monitor, track, and control the movement of objects and personnel to ensure that authorized objects and personnel are in authorized zones at authorized times. With increased security concerns worldwide, expanding movement of goods and people, and more complex logistics, the need for monitoring, tracking, and control have become a critical factor.

However, when an unauthorized object or person appears in an unauthorized zone at an unauthorized time, unless an appropriate action is taken, simple detection is insufficient.

RFID systems are usually integrated with a client/server architecture in which intelligence resides on centralized servers and databases. In such systems, the RFID reader must communicate with a server and wait for a response before an action can be taken. If delays or bottlenecks occur in the network, the response is delayed. When the server or network is unavailable, the system ceases to function. Therefore, the ability of an RFID system to provide an appropriate response depends on the ability of the centralized system to provide communications and validation.

RFID systems can be implemented with distributed intelligence to enable local decision making near the readers. This approach provides faster response to events while minimizing network traffic and dependence upon centralized servers, thereby improving the response, reliability, and availability of the network.

This paper describes how holonic intelligence, a special case of distributed intelligent system technologies, can be implemented to automate data collection for service queues, track and control personnel and goods, monitor and control inventory, and use dynamic digital signage for information dissemination.

II. DISTRIBUTED INTELLIGENT SYSTEMS

Centralized networks are built on client/server network architectures in which information and decision making rules and policies are stored on servers and are passed from client to client via servers.

This approach can be viewed as centralized communications with centralized intelligence. However, it has two major weaknesses:

- Lack of robustness because the entire network depends on the availability of the server to provide communications as well as access to information and intelligence. When communications to the server or the server itself is compromised, the entire network ceases to function;
- Lack of scalability because the network must be reconfigured when new nodes are added. Since additional nodes may increase communications, network bandwidth may become a bottleneck.

Distributed intelligent systems are based on two characteristics that distinguish them from centralized client/server systems: distributed communications and distributed intelligence.

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Unlike centralized systems, where each node communicates with other nodes via a server, each node in a distributed communications network is capable of communicating with nodes that are within its communication range. If a node needs to communicate with a node that is out of communications range, it may be possible to do so by multi-hopping. Depending on the density of the network, a source node may be able to access the destination node using alternate paths.

This feature of distributed communications networks has the following advantages:

- Improved scalability because new nodes can be added to the network, thus increasing its density within a given range or extending the range of the network;
- Improved robustness because alternative routing paths are available for moving information from a source node to a destination node, thus mitigating potential failures and bottlenecks;
- Throughput performance improves with the density of the network, contrary to centralized systems;
- Integration with centralized systems is facilitated because any node on a distributed communications network can be directly connected to a centralized communication system.

A useful method for providing distributed decision making at each node of a network is Holonic Intelligence, a collaborative agent technology that was introduced by Arthur Koestler in *The Ghost in the Machine* [1] and developed by the Holonic Manufacturing Systems Consortium, a major international research program of the Intelligent Manufacturing Systems Program [2].

The functionality of a Holonic Intelligence System is analogous to that of an ant colony. Whereas a single ant has a limited level of intelligence for following a pheromone deposited by another ant, finding a shorter path, and leaving a pheromone for other ants to follow, an ant colony has a higher capability emerging from the collective intelligence of individual ants that communicate and cooperate in order to adapt to changing circumstances. Thus, the intelligence of the colony as a whole emerges from basic interactions between ants and the simple intelligence replicated in each ant. Similar phenomena can be observed in team sports where players communicating and collaborating can be more effective than individual star players.

Key aspects of holonic systems are as follows [3,4,5]:

- They involve both hardware and software;
- They utilize collaborative agent technologies for the software component;
- Soft computing techniques such as fuzzy logic, genetic algorithms, and multi-criteria optimization can be employed to implement local intelligence;
- Negotiation techniques such as bilateral auctions and contract net protocols are used to enable coordination of agents;
- Holonic Intelligence Systems have system level objectives that are achieved through coordinated decisions made locally at individual nodes. This permits each node to adapt to specific requirements while fulfilling system objectives.

Holonic Intelligence Systems have the advantages of robustness, scalability, and they facilitate integration with client/server systems [6,7,8].

A. *Holonic Intelligence Platform*

To develop a distributed intelligent system, we use an integrated wireless hardware and software platform to coordinate nodes within the network [9]. The Holonic Intelligence Platform consists of the following hardware components and software as described in Fig. 1:

- A computer processor and operating system to locally execute Holonic systems software;
- On-board memory for local storage of data and other information;
- A wireless transceiver utilizing industry standard protocols for peer-to-peer communications between nodes;
- Holonic systems software to enable intelligent routing between nodes, locally store and process information, and provide local decision support in response to detected events. Holonic systems software enables neighboring nodes to cooperate and coordinate decisions affecting more than one node. It also provides the capability to exchange information without having to access centralized servers, but having full access to servers when necessary [10,11,12,13].

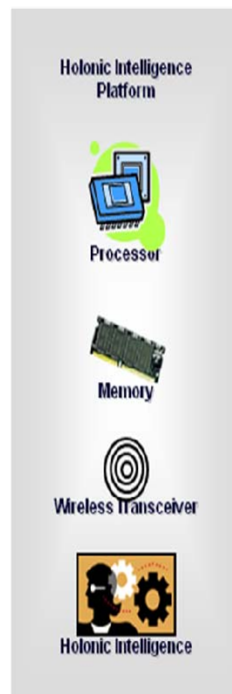

Figure 1. Holonic Intelligence Platform

The Holonic Intelligence Node consists of a Holonic Intelligence Platform with RFID readers and other sensors as inputs, and audio/video and actuators as outputs (Fig. 2). With on-board processing, memory, and peer-to-peer communications, a Holonic Intelligence Node provides functionality for local communications and control that can be customized for a broad range of applications.

B. Holonic Intelligence Node

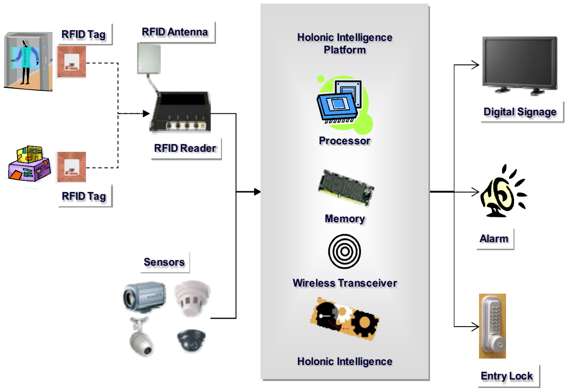

Figure 2. Holonic Intelligence Node

C. Holonic Intelligence Tower

The Holonic Intelligence Tower is a portable, self-contained unit that can be rapidly deployed to create a wireless peer-to-peer network with RFID readers, digital displays, and other input/output devices for specific applications. Since the transceiver in the Holonic Intelligence Platform utilizes industry-standard communication protocols, a network of Holonic Intelligence Towers can be connected to a centralized system to exchange and process data. The Holonic Intelligence Tower includes the following components:

Biometric Module for fingerprint and face recognition;

Audiovisual Module with digital displays to deliver high-resolution images, full motion video with audio, or simple character displays;

Data Entry Module with a digital tablet, keyboard/trackball, or touch screen for data entry;

RFID Module with an RFID reader and antennas for active or passive tags with appropriate transmission frequencies (LF, HF, or UHF) for the application;

Holonic Intelligence Platform consisting of a microprocessor, flash memory, wireless transceiver, and Holonic systems software;

Power Module for powering all components by 120/240 VAC or a rechargeable battery.

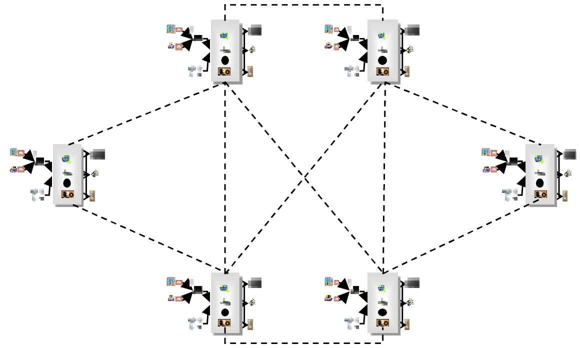

Figure 3. Holonic Intelligence Network

Holonic Intelligence Platforms can be wirelessly connected in a network as shown in Fig. 3. One or more of these nodes also be connected to a server to collect, process, and disseminate data for billing and other corporate needs.

III. DISTRIBUTED INTELLIGENT RFID SYSTEMS

A. Tracking and Control of Personnel and Goods

Traditionally, RFID tracking of personnel and goods is accomplished with a centralized systems architecture in which every event is transmitted to a host computer for validation. If the connection to the server fails the system ceases to function because there is no local intelligence available to make decisions.

Access control technologies use electronic cards that are validated through a centralized database and connected to card readers. If the connection to the centralized database fails, the system cannot function because it lacks information to continue the validation process.

Bar coding is one of the most popular technologies for tracking assets. However, bar coding also depends upon access to centralized database servers to validate and record transactions. Although handheld bar code scanners may locally store information, validation cannot occur until the scanners are connected to database servers.

Because a Holonic Intelligence Network avoids the need to access centralized databases for each transaction it is more robust compared to a centralized architecture. Centralized databases can integrate all transactions occurring at individual check points by the wireline or wireless communications capability built into the Holonic Intelligence Platform.

The Holonic Intelligence Platform enables connectivity to input devices such as bar code scanners, RFID readers, audio/video devices, CCTV systems, biometric readers, and output devices such as audio/video devices, alarms, and locking mechanisms.

Holonic Intelligence provides a means to implement a scalable system in which nodes can be quickly added at check points without having to install fixed wiring and reconfigure the system. This solution is more robust because it does not require access to a centralized database for each transaction. Because the Holonic Intelligence Platform provides local processing and data storage, and has standardized input/output ports (serial, USB, VGA), devices can be connected to implement personnel, asset tracking, and access control.

B. Inventory Tracking and Control

Inventory management is a specialized case of asset or product tracking. It is key to successful warehousing, distribution, and manufacturing operations. Traditionally, bar-code technology has been used for inventory management, however, many companies are now incorporating RFID.

Most of these systems rely on centralized database servers and client/server communication to establish communications between bar code scanners and RFID readers, . Typically, the infrastructure used for such systems is based on fixed wiring and is therefore difficult to reconfigure to meet the changing requirements of business.

The Holonic Intelligence Platform provides the ability to flexibly deploy inventory tracking with wireless and wireline connectivity, distributed networks, and enable local transaction processing and control.

By providing local intelligence at each reader location, faster and more secure response is obtained without the need to access a centralized database for each event. This approach is not intended to replace legacy client/server systems, but rather to extend and enhance their functionality.

C. Dynamic Digital Signage

Traditional advertising sends generic information to its audience regardless of the context. Digital signage has made it possible to change the information being sent depending upon the time and place, however, most current systems employ centralized servers to send preprogrammed advertising.

Dynamic digital signage systems convey advertising or product/service information that is specific to customer needs. Frequently, merchandise is tethered by a cable that activates a switch to display information for the product selected by the customer. Non-contact systems activated by RFID tags are also being utilized.

The difficulty with such approaches is that they use traditional client/server architectures with centralized database servers to distribute information. This approach requires that the communication system and centralized servers are always available and that communication bandwidth and processing power are sufficient to accommodate the customer activated requests.

The Holonic Intelligence Platform is specifically designed for high bandwidth applications such as video. It has a microprocessor and memory to locally store and process information at each node, thus significantly reducing dependence on the communication network and availability of the server.

Applications of the Holonic Intelligence Platform are automated data collection at airports, shopping malls, retail stores, distribution warehouses, supply chains, manufacturing and service industry such as banking, hospitals, and the hospitality industry.

D. Automated Data Collection for Service Queues

Managing service queues is one of the most important tasks for ensuring quality customer service. Queue length and waiting time are key parameters to measure the effectiveness of service. Traditionally, these statistics are gathered manually. In the majority of cases, however, queues are managed by trial and error. Service organizations attempt to balance the cost of providing service versus customer satisfaction. Changes in procedures for airport security screening, for example, can have a great impact on controlling queue length and waiting times, and, therefore, the ability of the airport to manage passenger flow.

Currently, airports employ manual surveys for short periods of one week or less to sample passenger flow through the security screening stations for the purpose of estimating personnel requirements.

Fig. 4 illustrates how automated data collection can be implemented for security screening. A system of Holonic Intelligence Towers containing RFID readers are located at the following points:

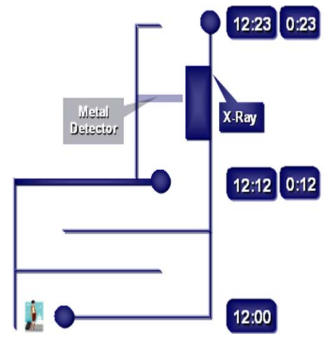

Figure 4. Airport Passenger Screening

- At the entry point of the queue;
- Where passengers place carry-on luggage on the conveyer for x-ray scanning and before proceeding through the metal detectors;
- Where passengers collect carry-on luggage and leave the security screening area.

By this configuration, data related to queue service time, delays, and queue lengths can be collected for subsequent analysis. In addition, digital signage also can display passenger waiting times based on data being collected.

Furthermore, if passenger carry-on luggage, laptops and personal items are tagged at the check-in station, data can be collected to ensure that passengers are entering appropriate security areas and are carrying items that belong to them.

In a similar manner, surveys can be conducted at banks, grocery stores, fast food restaurants, and other places where the analysis of service queues and service times is important.

IV. Future Opportunities and Conclusions

The adoption of RFID technologies is increasing as organizations discover their benefits and the costs of implementation decrease. RFID systems need to cover larger and more difficult to reach areas and be more adaptable to meet the operating demands of new applications. These systems have to respond quickly and be available 24/7. Distributed RFID systems have the potential to provide increased scalability, adaptability, and robustness, and provide decision making at the point where tags are interrogated.

Using the analogy of an ant colony, individual ants have only a limited level of intelligence, and yet the colony has a much higher level of intelligence that allows it to survive.

In the past, intelligent systems research has often focused on incorporating levels of complexity. However, the intelligence residing in centralized servers does not allow for cooperation and coordination between individual nodes. Methods are needed to distribute the simplest level of intelligence in individual agents. Coordination algorithms are needed to enable a higher level of intelligence to emerge in the overall system.

The challenge is to develop effective methods for determining the form of simple intelligence that can be built into individual agents and determine the interactions that are required between them so that the desired degree of emerging intelligence is achieved. A corollary is to ensure that undesirable systems behavior does not emerge, and, if it does, to detect and mitigate such behaviors. Understanding of biological systems in nature provides excellent opportunities for future research [14,15].

As described in Section III of this paper, the use of distributed communications combined with distributed intelligence creates new opportunities for RFID systems that are difficult to implement with traditional client/server architectures. Issues to be addressed include interoperability, selection of operating and communications protocols, integration with hardware and software, and generic applications software that can be quickly customized for specific customers.

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